CEL Hybrid Model

3-D Application

Analyze and Simulate the Movement Behavior of Juvenile Salmon in the Complex Approach Hydraulic Fields of Fish Bypass Systems

Method for Analyzing & Predicting Juvenile Salmon Swim Path Selection

CEL Hybrid Modeling

Numerical Fish Surrogate

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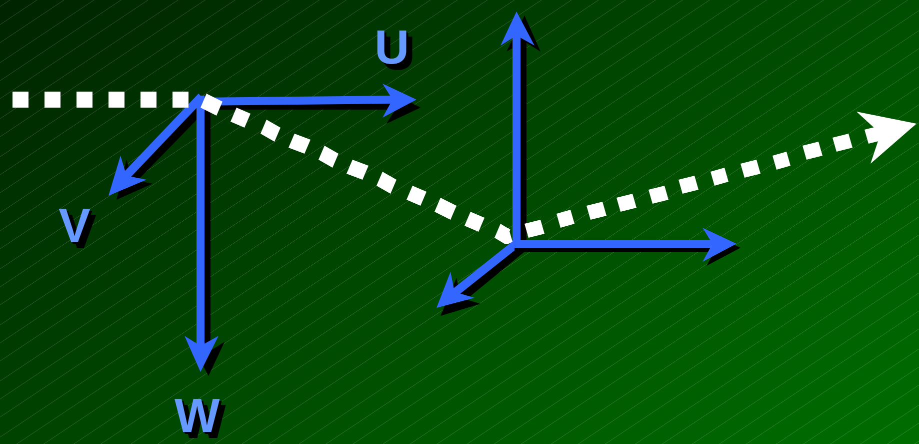
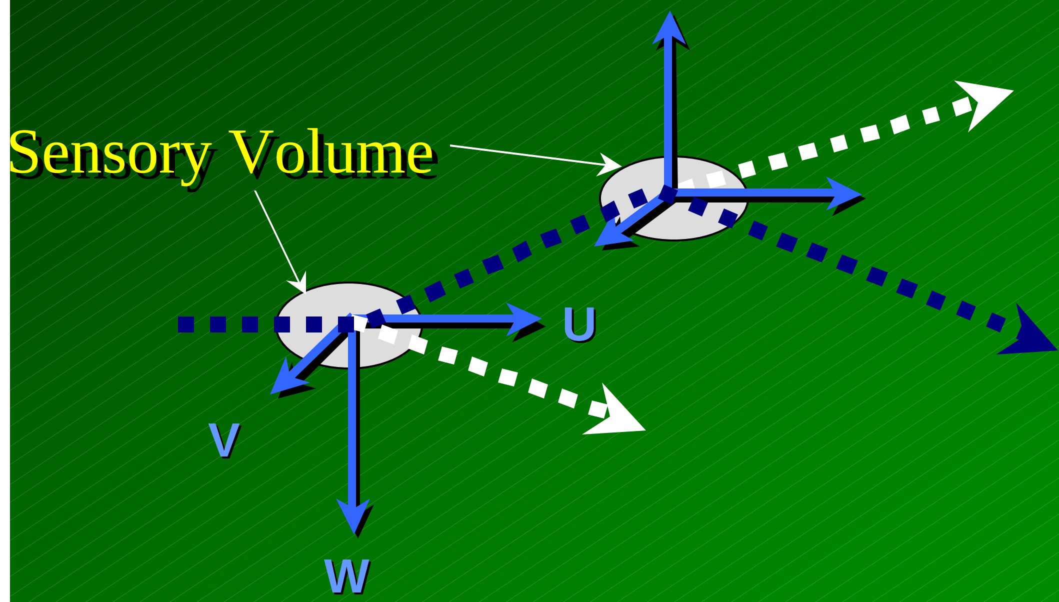
Mathematical Description of Movement



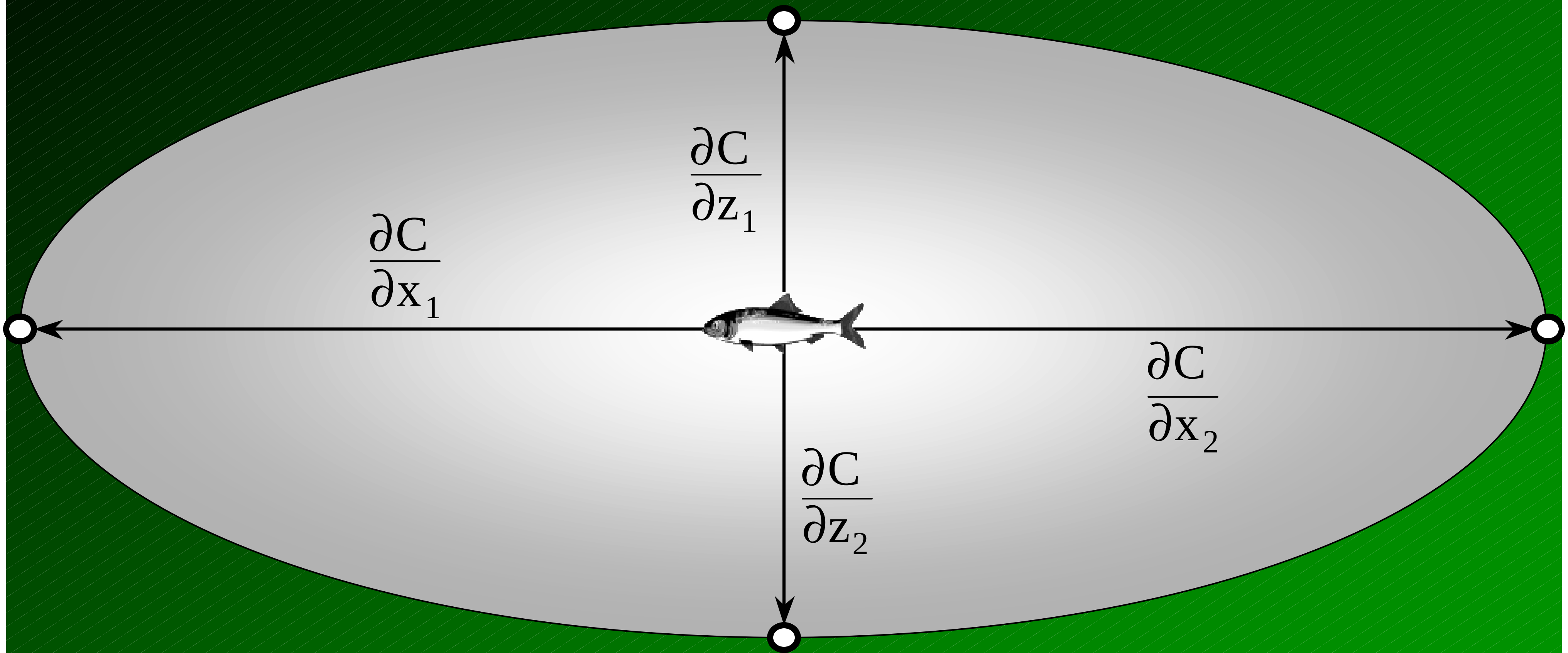
Passive Particle

$$X_{t+1} = X_t + U^*Dt$$
$$Y_{t+1} = Y_t + V^*Dt$$
$$Z_{t+1} = Z_t + W^*Dt$$



Active 'Particle'

$$X_{t+1} = X_t + (U + U_{fish}) * Dt$$
$$Y_{t+1} = Y_t + (V + V_{fish}) * Dt$$
$$Z_{t+1} = Z_t + (W + W_{fish}) * Dt$$



C = { e.g., velocity and/or acceleration vectors, temperature, dissolved oxygen, turbulent kinetic energy, turbulent length scales, pressure, etc. }

Integration for Analysis and Simulation

3-D Computational
Fluid
Dynamics

Couple:

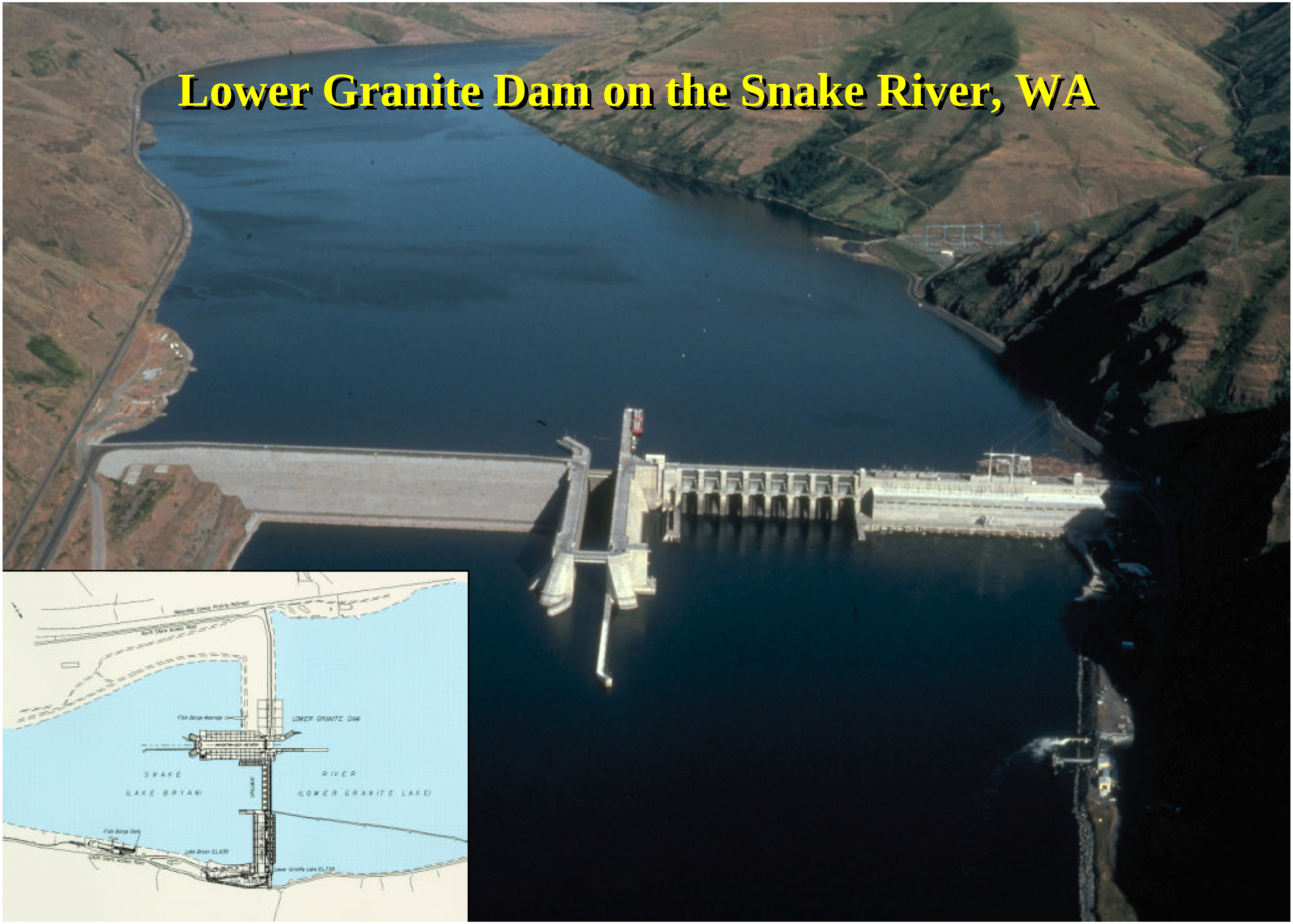
Numerical Fish Surrogate

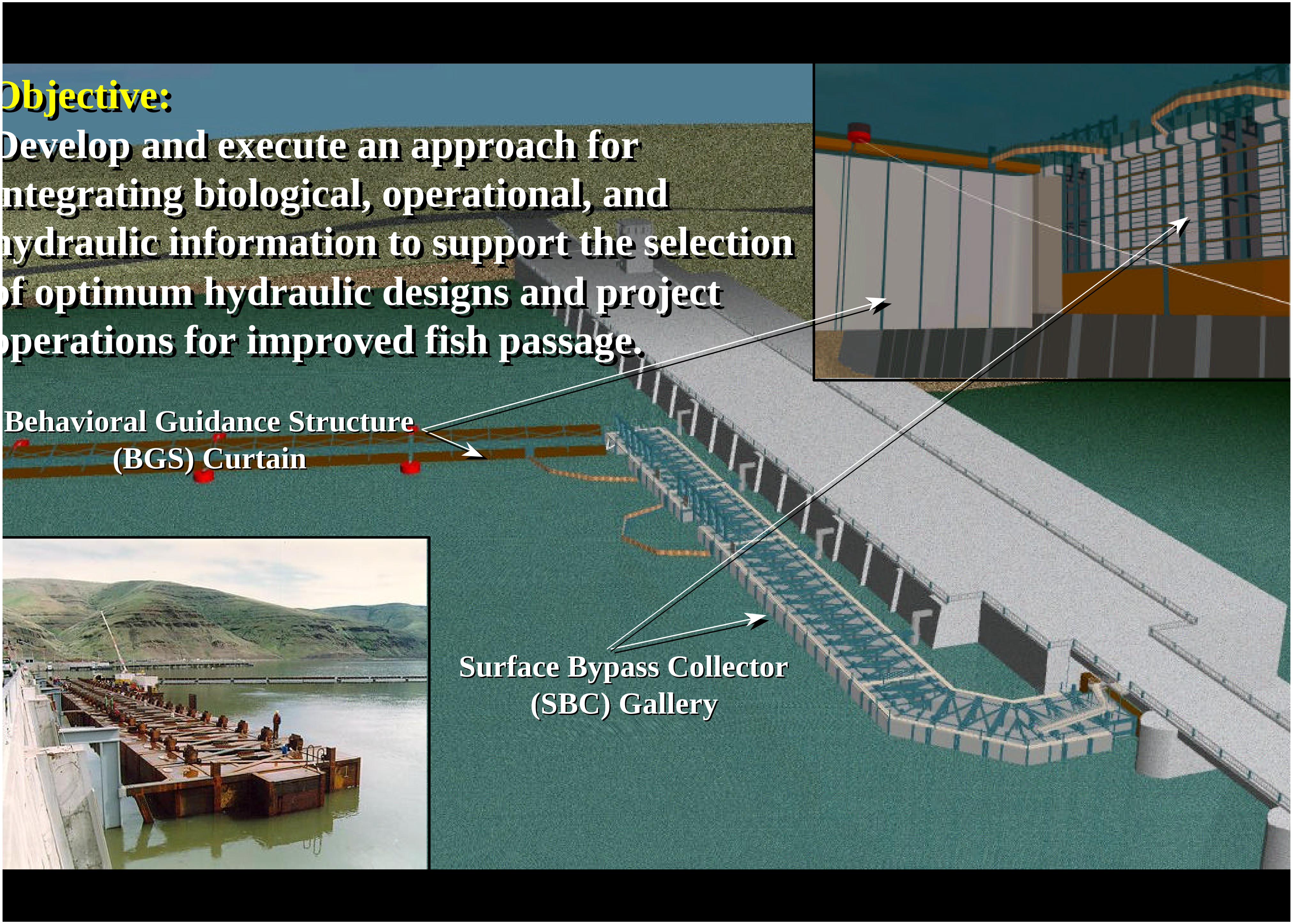
3-D Biological
Tracking
Data

Numerical Fish Surrogate Methodology:

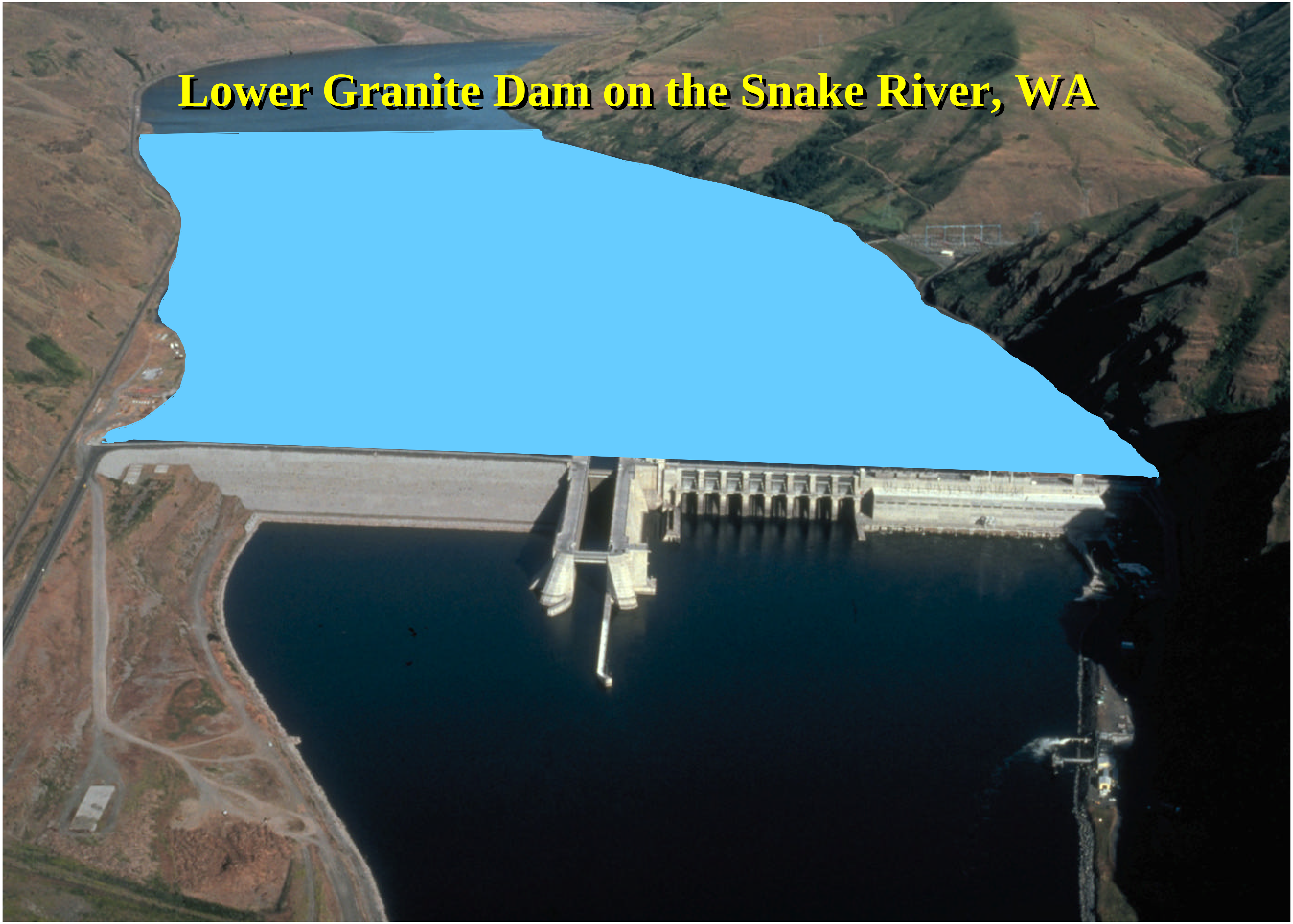
Data Integration
Data Mining and Analysis
Simulation
Optimization
Graphics

Lower Granite Dam on the Snake River, WA

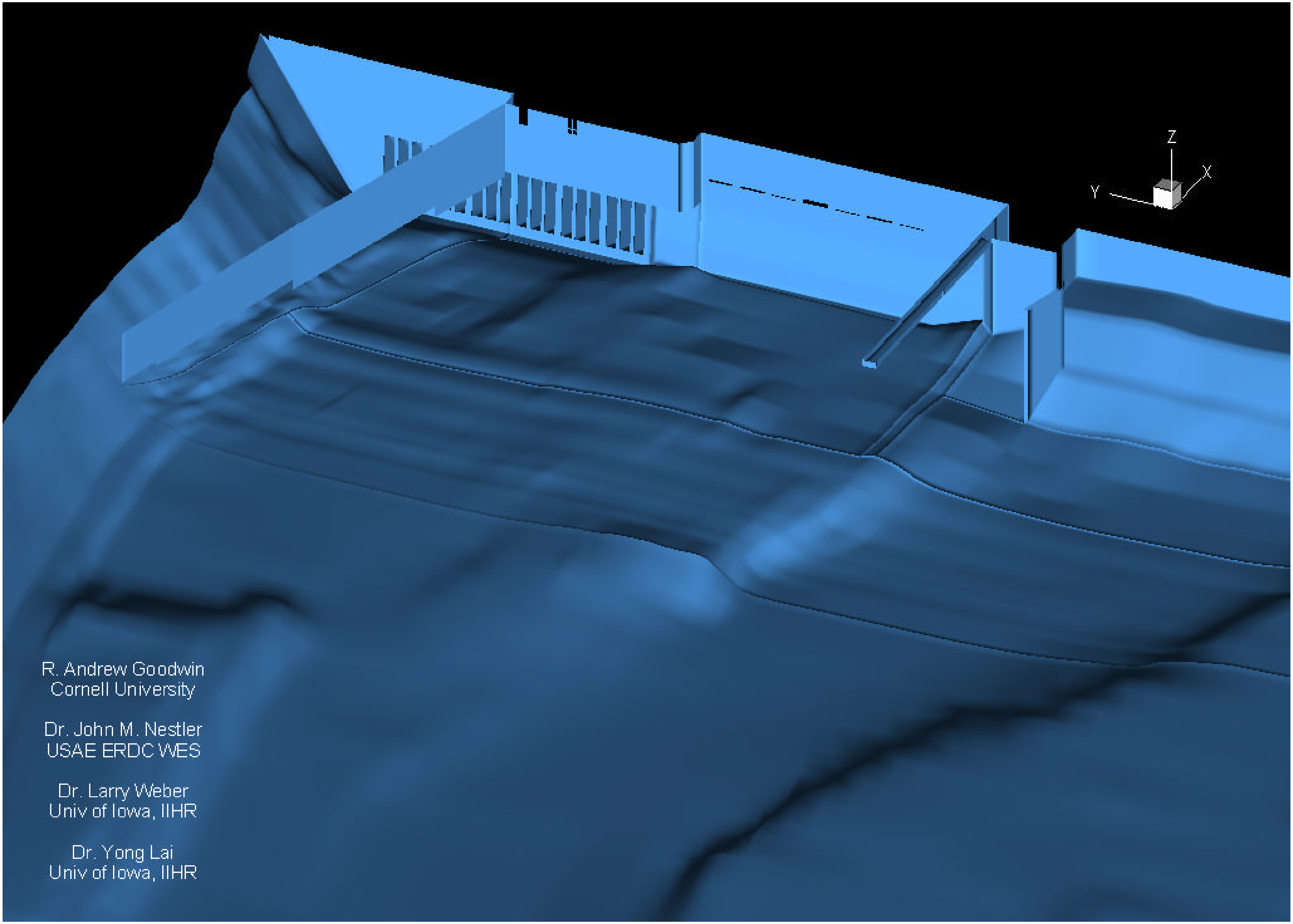




bjective:
evelop and execute an approach for
ntegrating biological, operational, and
ydraulic information to support the selection
f optimum hydraulic designs and project
perations for improved fish passage.
Behavioral Guidance Structure
(BGS) Curtain
Surface Bypass Collector
(SBC) Gallery


Lower Granite Dam on the Snake River, WA

Boundary of 3-D Computational Fluid Dynamics (CFD) Model Grid


Z
Y
X
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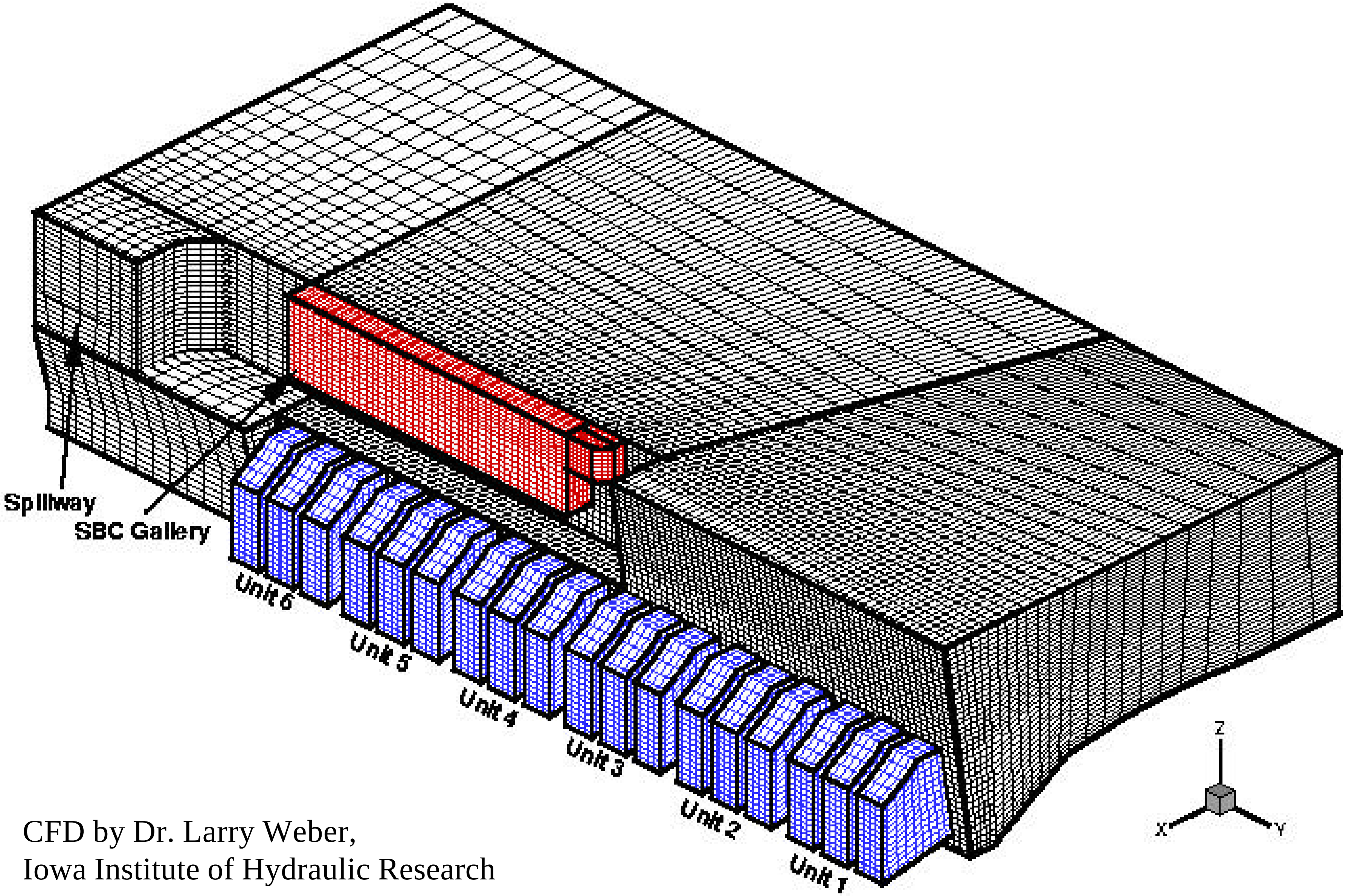
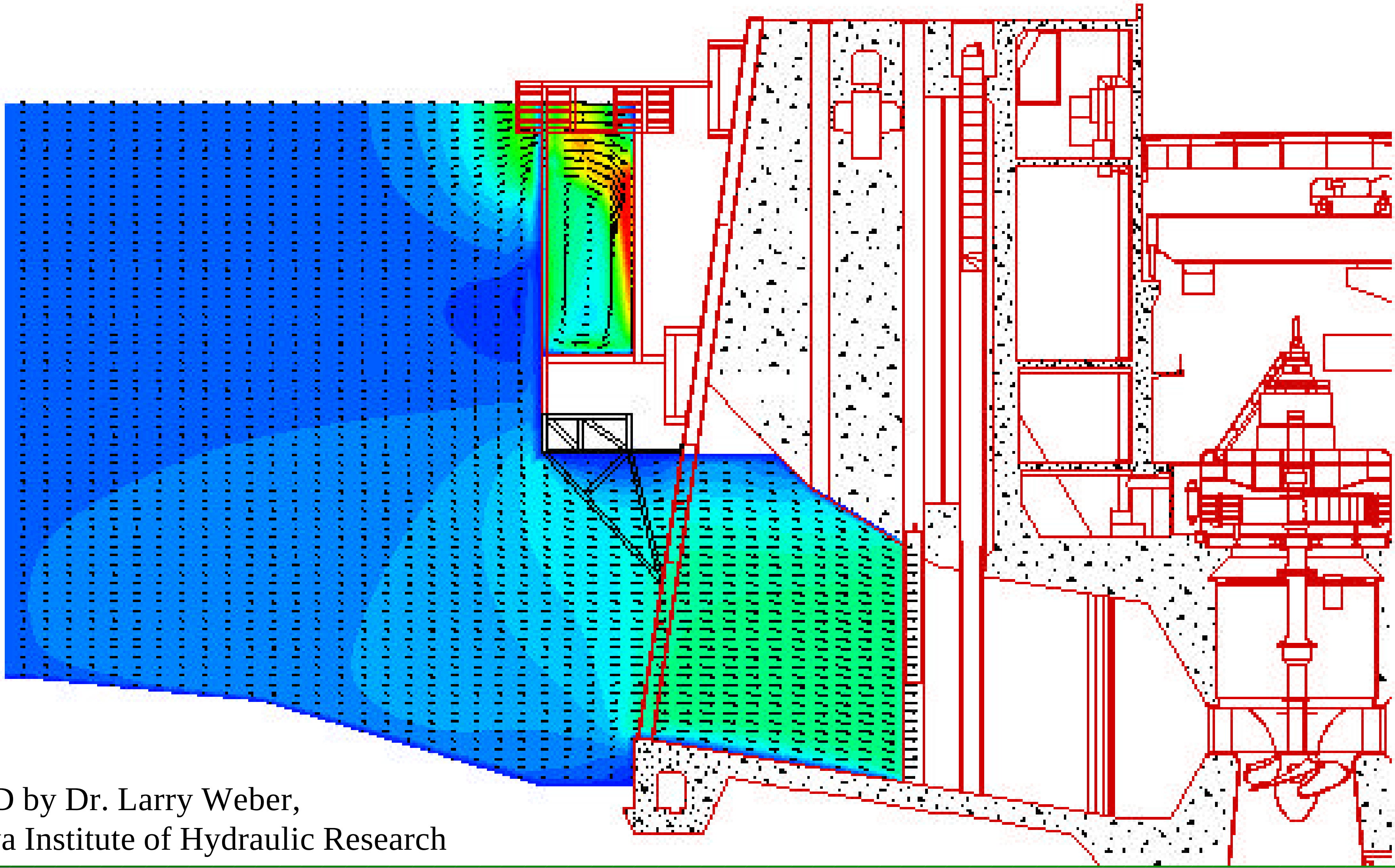
Computational Fluid Dynamics Simulation of Flow



CFD by Dr. Larry Weber,
Iowa Institute of Hydraulic Research

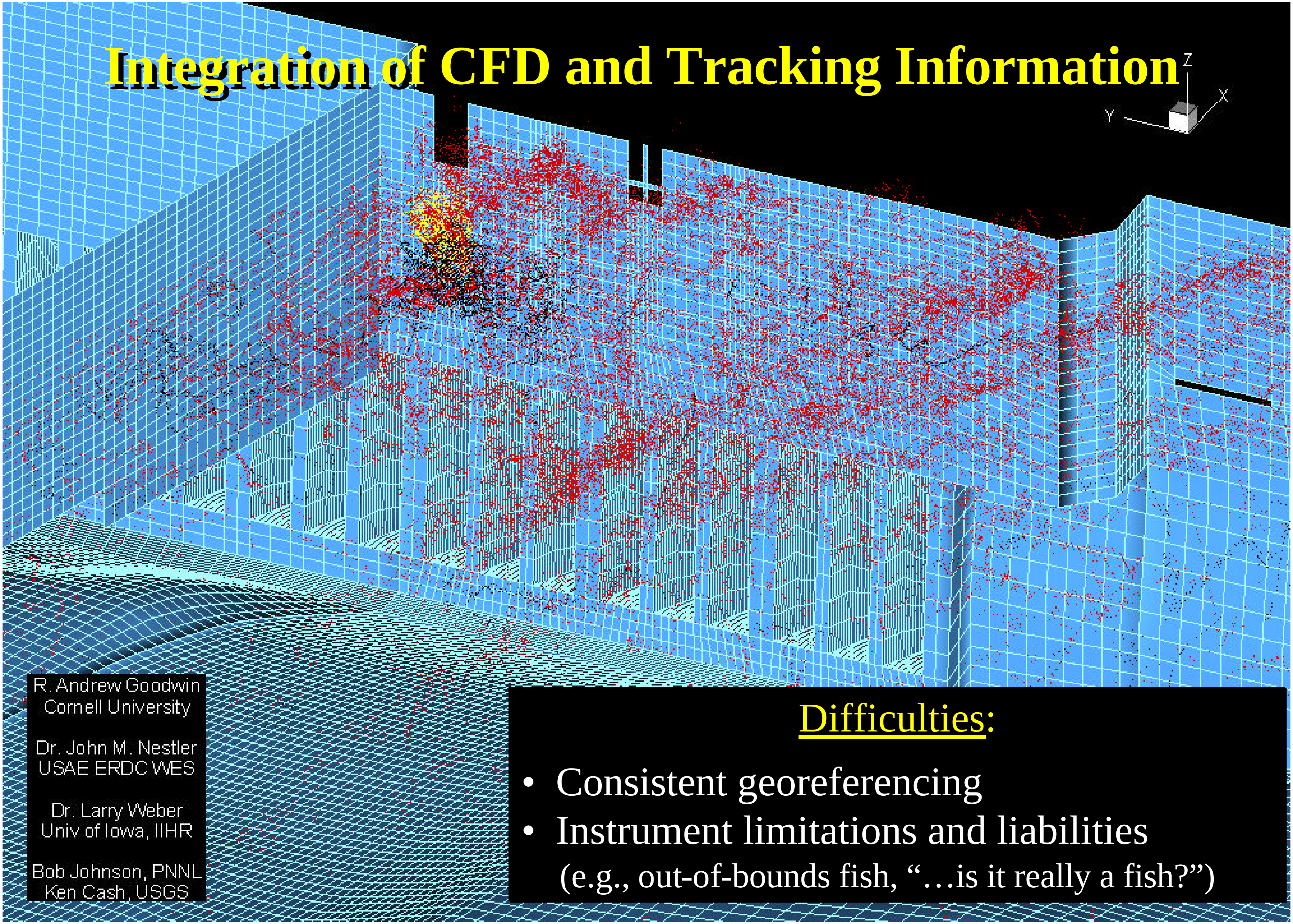
Flow Conditions Near Orifice of Surface Bypass Collector

Example



CFD by Dr. Larry Weber,
Iowa Institute of Hydraulic Research

Integration of CFD and Tracking Information



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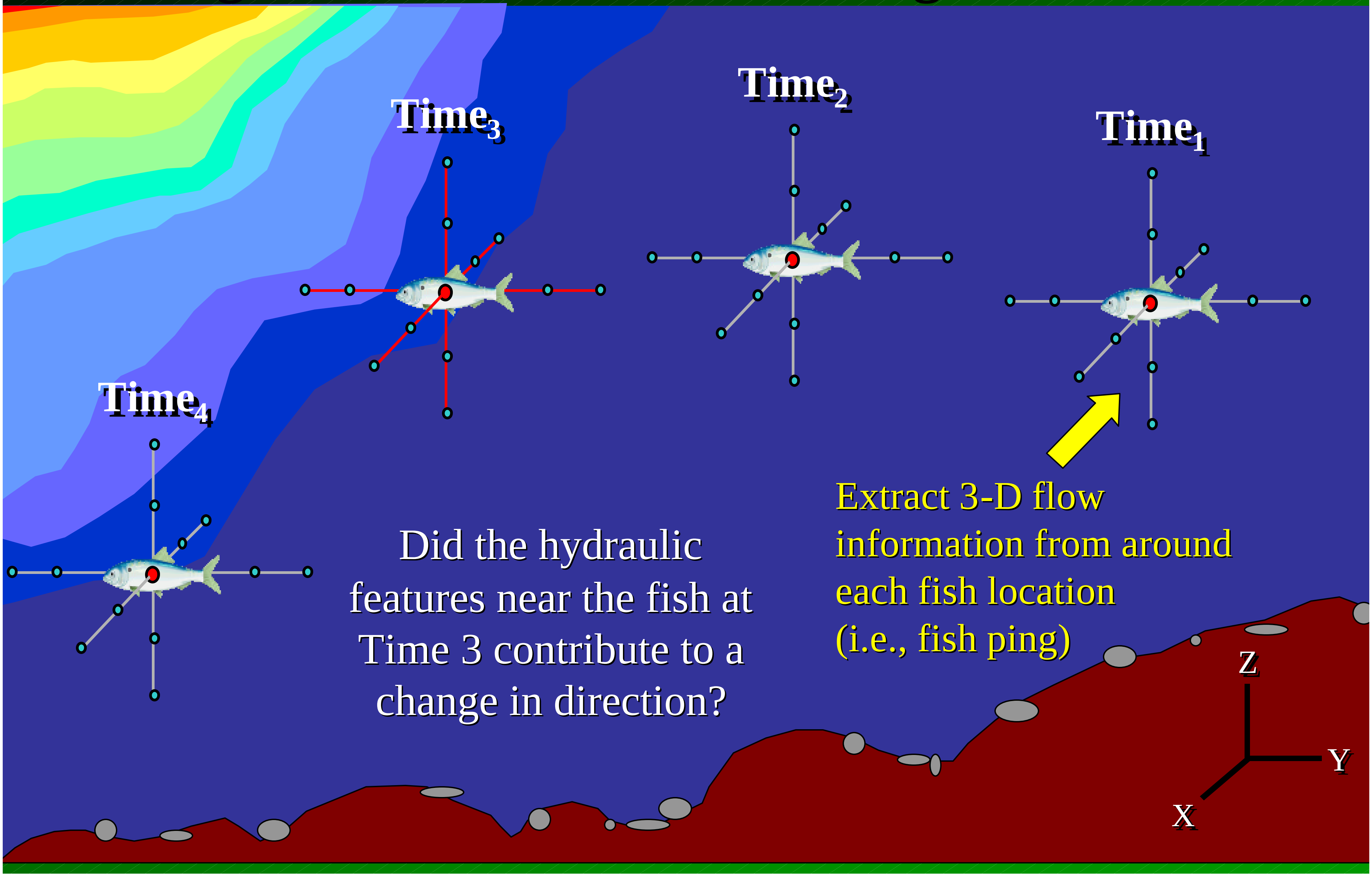
Bob Johnson, PNNL
Ken Cash, USGS

Difficulties:

- Consistent georeferencing
- Instrument limitations and liabilities
  (e.g., out-of-bounds fish, "…is it really a fish?")

Integration of CFD and Tracking Information

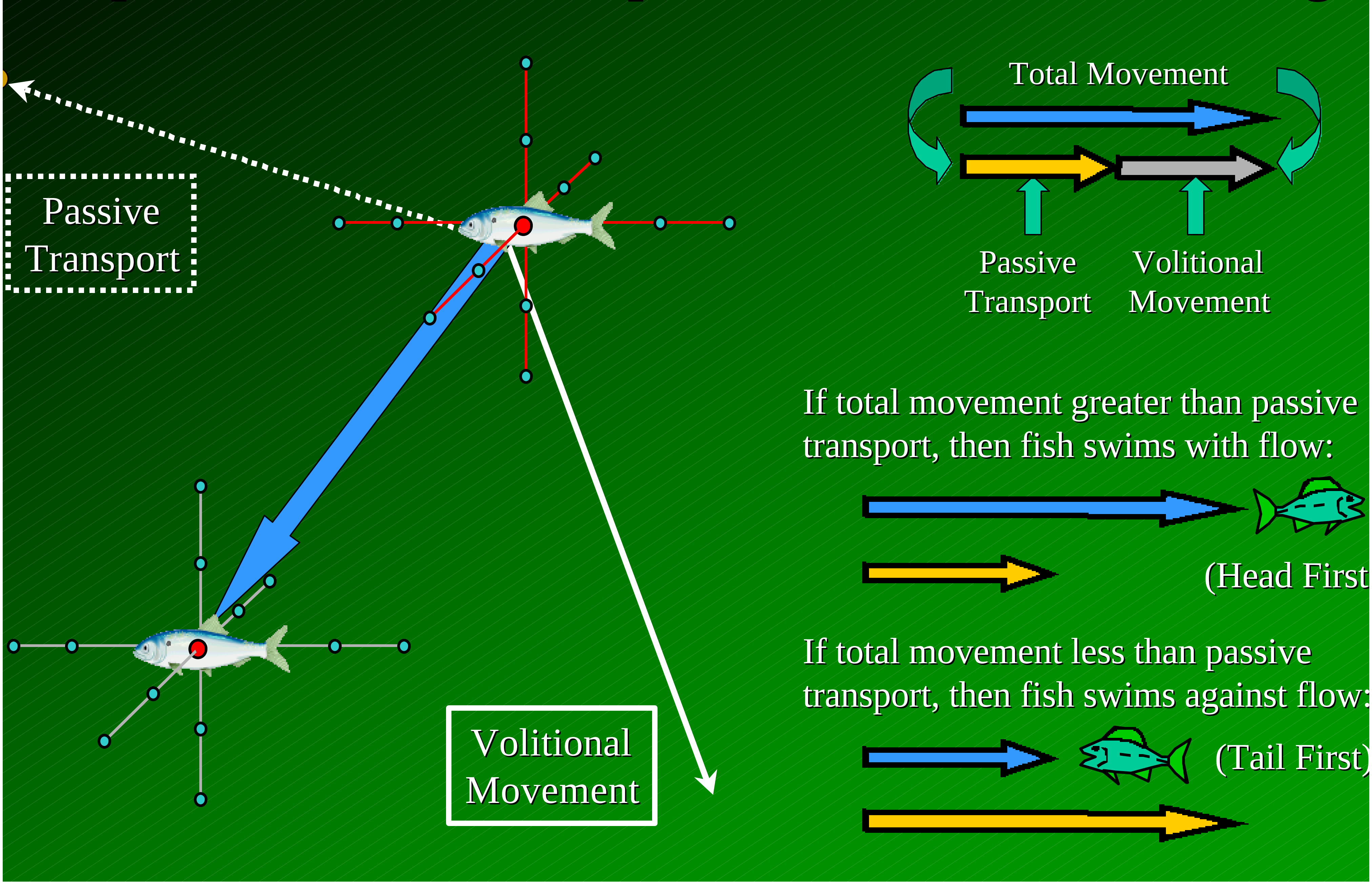


Numerical Fish Surrogate
(Real System)

NFS Data Integration Module

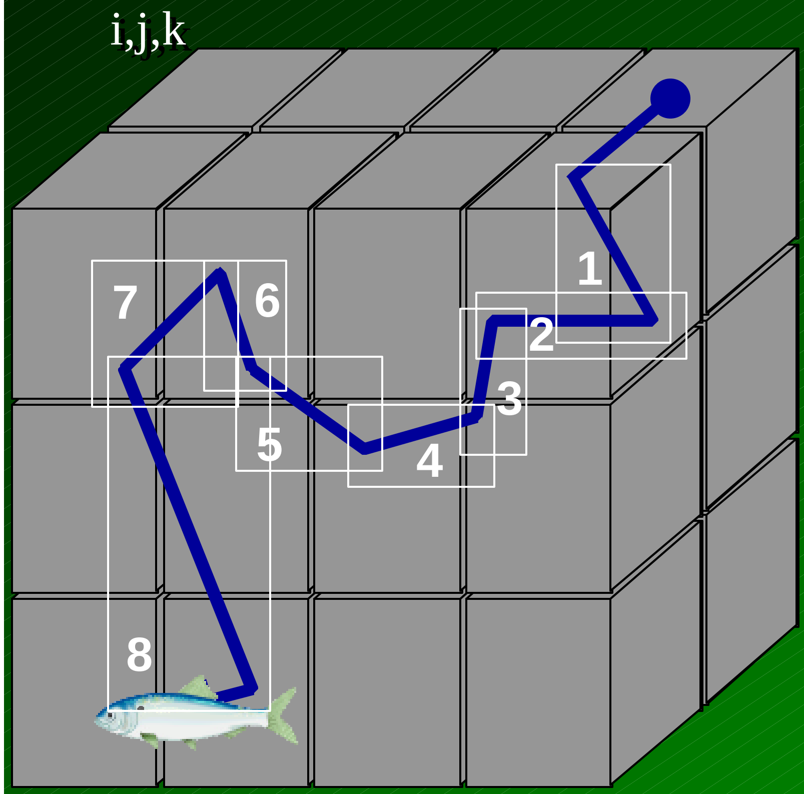
- Locates points in distorted 3-D CFD computational cells
  - Calculation of and interpolation of flow values to fish-oriented sensory points
- Determines whether points are in-bounds or out-of-bounds
- Calculates 19+ fish movement variables in 3 reference frames
- Calculates 146+ potential forcing functions
  - 44 variables at user-defined number and location of sensory points
- Uses Cartesian-contravariant space for efficient computations
  - Large data sets V-E-R-Y memory intensive
  - Improves program speed
  - Reduces computational requirements
- 7,000+ lines of FORTRAN 90 code
- Advanced 3-D Tecplot and MATLAB graphics
  - Graphical analyses of multi-scaled data

Separate Passive Transport & Volitional Swimming



Obtain Position Pairs

Observations 1-8



Note: Autocorrelation & other biases

For a constant time step:

New Position$_x$ = Old Position$_x$ + u + (u$_{fish}$ + random # + biases)

Multiple Regression Analysis (x, y, z):

$u_{fish} = b + \alpha_1$ (velocity) +

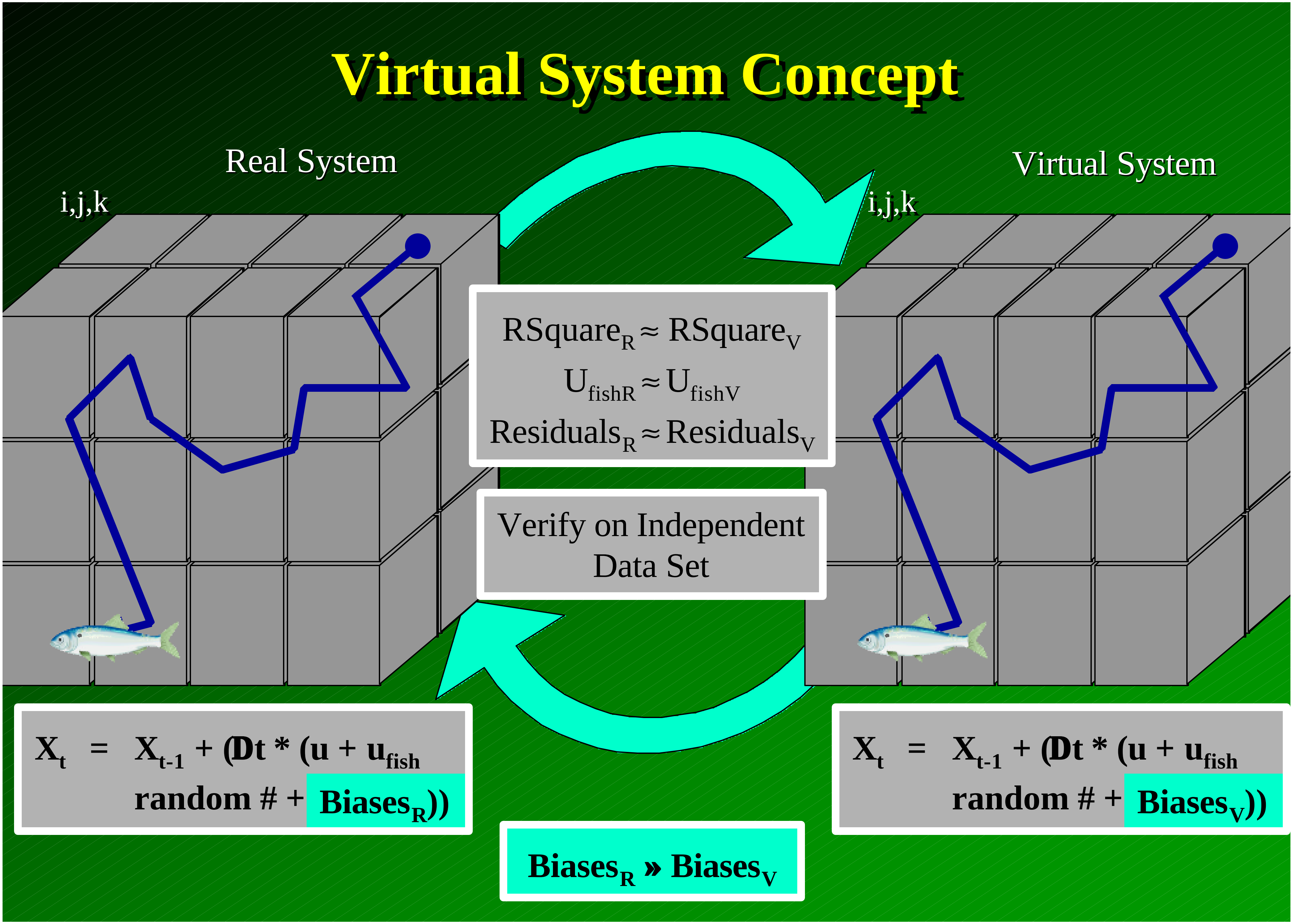
β_2 (acceleration) +

δ_3 (turbulence intensity) +

ε_4 (turbulence dissipation) +

ϕ_i (other hydraulic variables) +

γ_j (secondary variables)

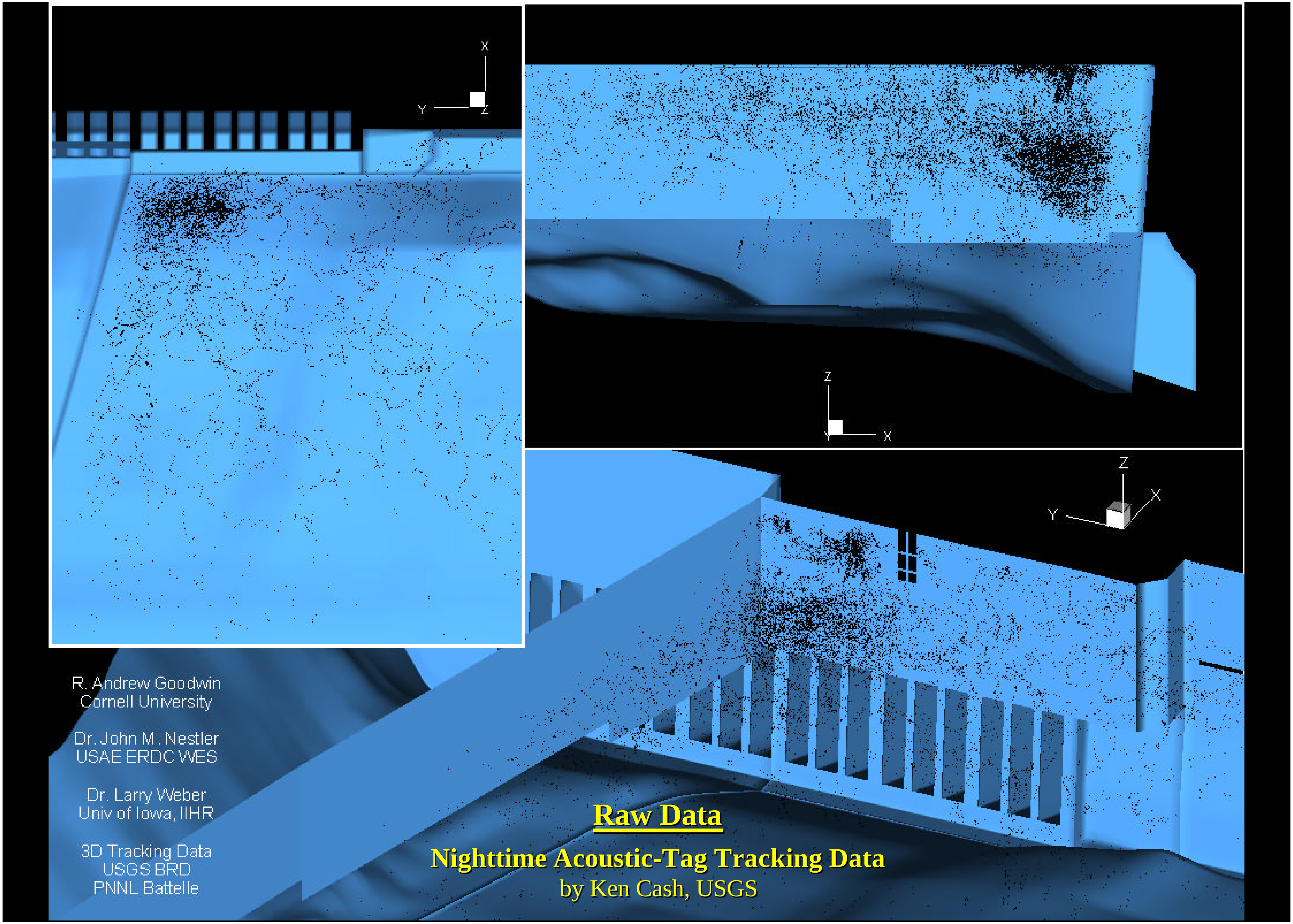

Virtual System Concept
Real System
Virtual System
i,j,k
i,j,k
$RSquare_R \approx RSquare_V$
$U_{fishR} \approx U_{fishV}$
$Residuals_R \approx Residuals_V$
Verify on Independent Data Set
X_t = X_{t-1} + (Ðt * (u + u_{fish} random # + $Biases_R$))
X_t = X_{t-1} + (Ðt * (u + u_{fish} random # + $Biases_V$))
$Biases_R$ » $Biases_V$

Numerical Fish Surrogate

(Virtual System)

NFS Simulation Module

- Fish movement relative to fish-orientated, not CFD, reference frame
- Uses Cartesian-contravariant space for efficient computations
  - Moves points (fish) within and between distorted cells and multiple blocks (for multi-block CFD)
  - Location of and interpolation of flow values to fish-oriented sensory points
  - Improves speed of V-E-R-Y memory intensive simulations
- 10,000+ lines of FORTRAN 90 code
  - 1500+ lines for behavioral (stimuli-response) rules
- Structured for quick substitution/revision of behavioral rules
- Structured for optimization procedure using NFS Data Integration Module
- 3-D animation


X
Y
Z
Z
Y
X
Z
Y
X
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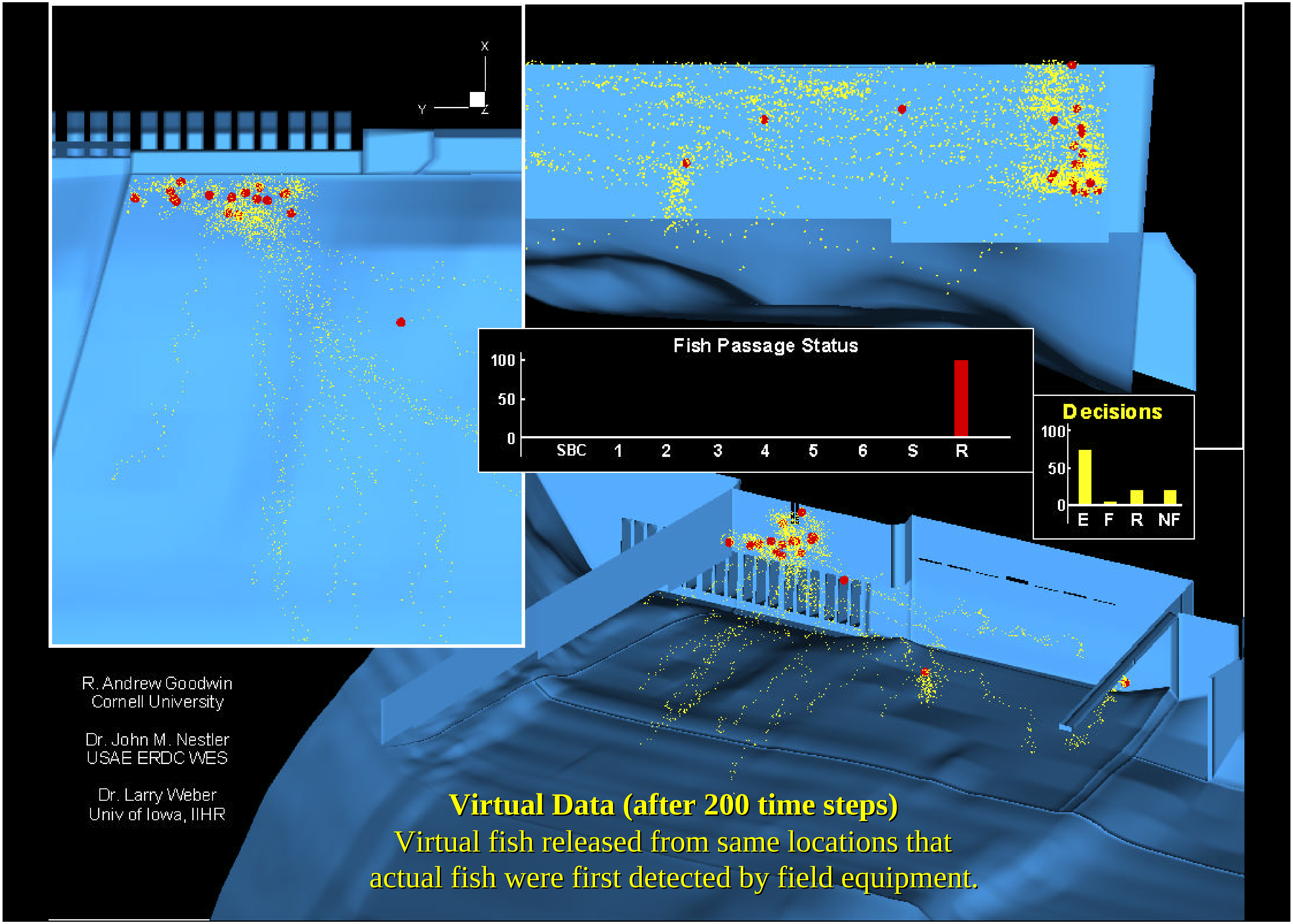
3D Tracking Data
USGS BRD
PNNL Battelle
Raw Data
Nighttime Acoustic-Tag Tracking Data
by Ken Cash, USGS


X
Y
Z
Fish Passage Status
100
50
0
SBC 1 2 3 4 5 6 S R
Decisions
100
50
0
E F R NF
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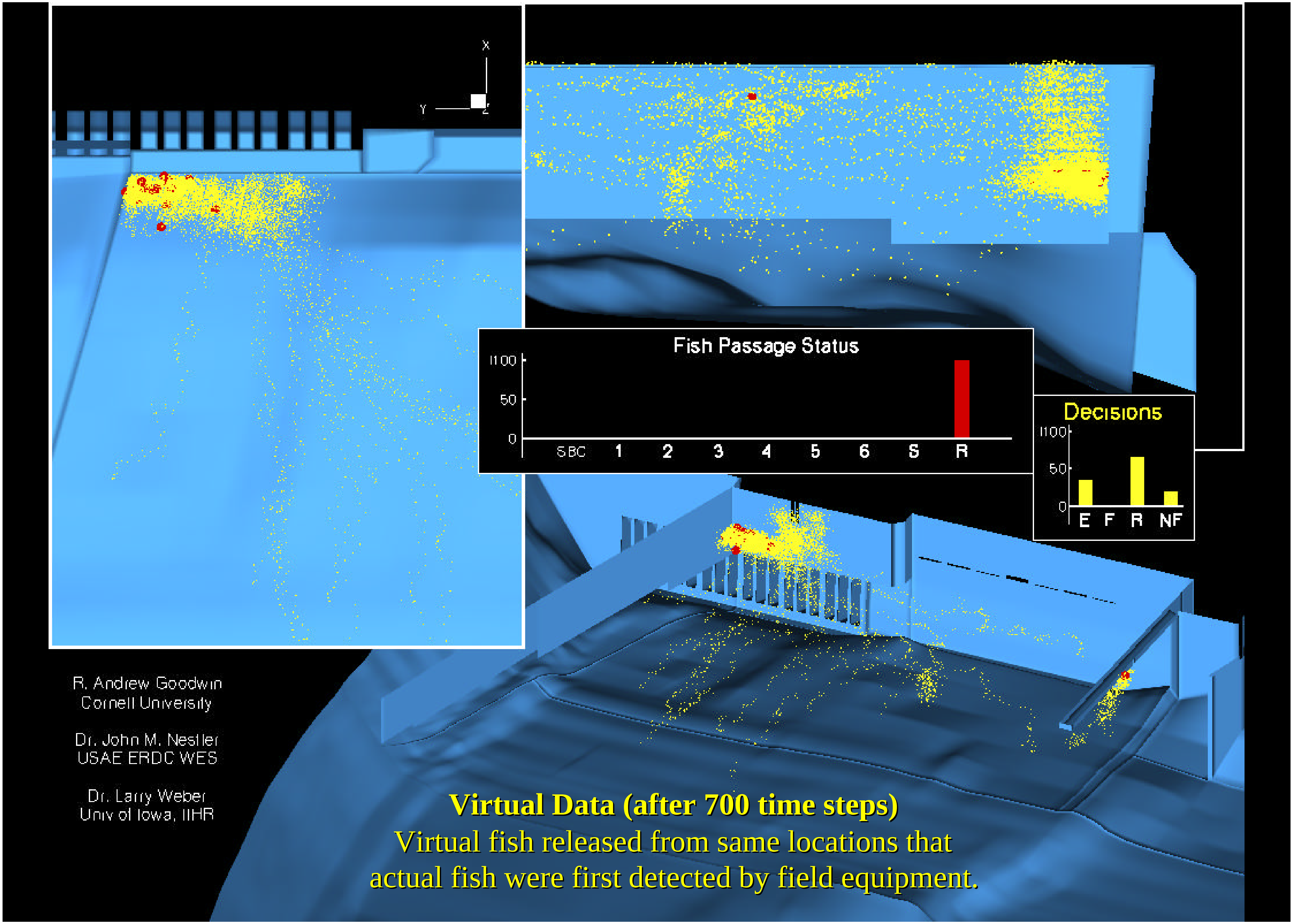
Virtual Data (after 200 time steps)
Virtual fish released from same locations that
actual fish were first detected by field equipment.



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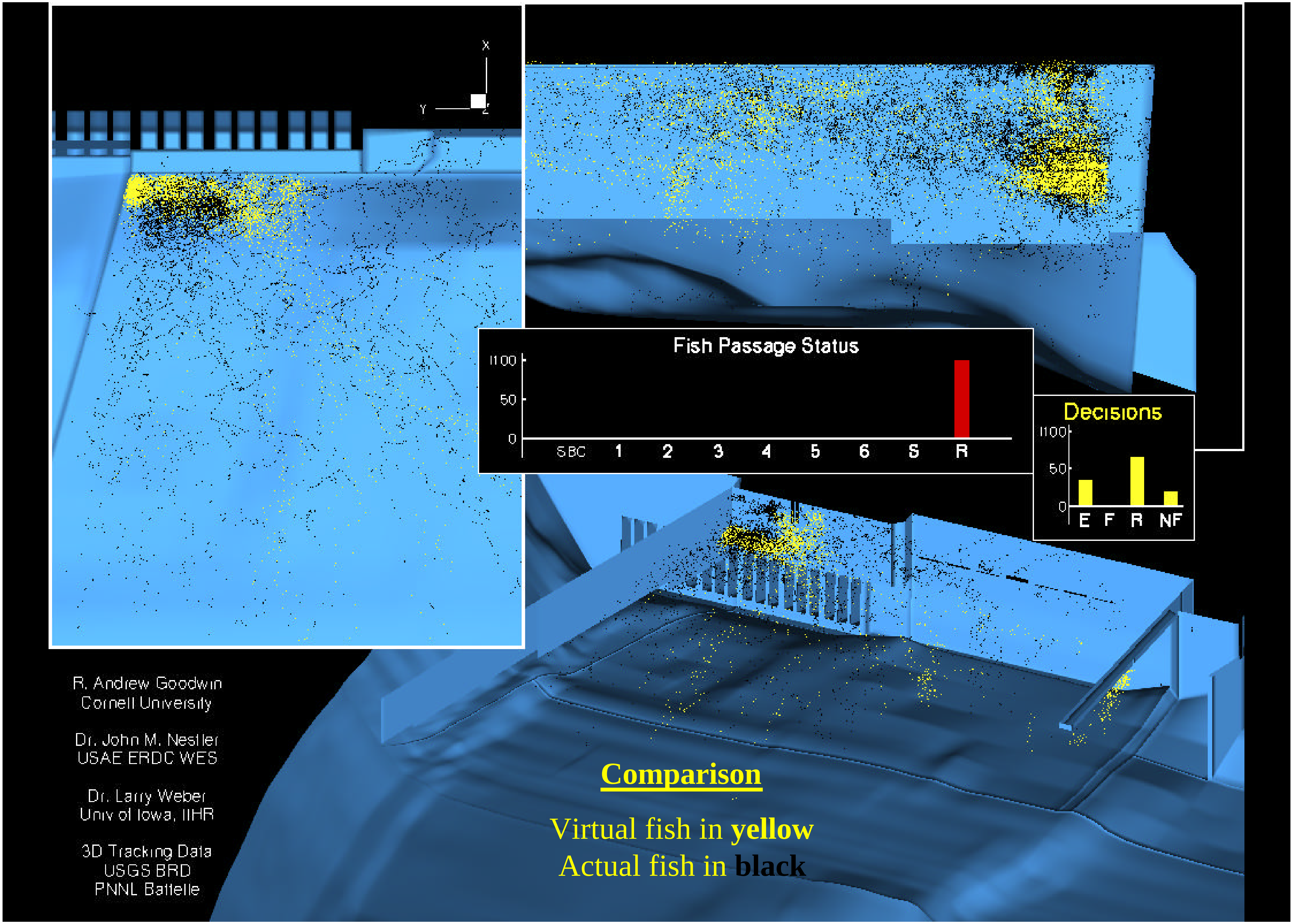
Virtual Data (after 700 time steps)

Virtual fish released from same locations that actual fish were first detected by field equipment.


X
Y
Z
Fish Passage Status
100
50
0
SBC 1 2 3 4 5 6 S R
Decisions
100
50
0
E F R NF
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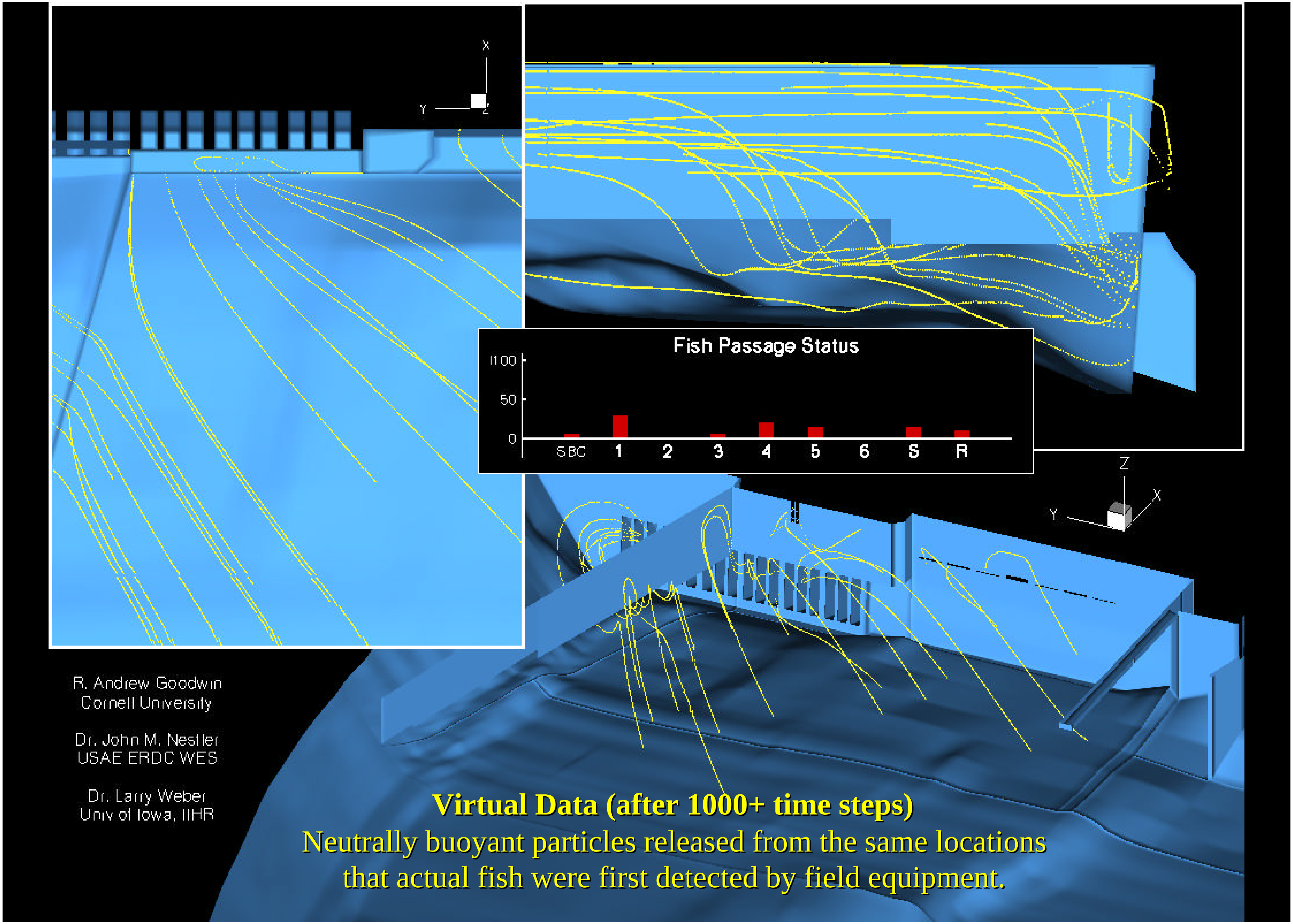
3D Tracking Data
USGS BRD
PNNL Battelle
Comparison
Virtual fish in yellow
Actual fish in black



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Virtual Data (after 1000+ time steps)

Neutrally buoyant particles released from the same locations that actual fish were first detected by field equipment.